Comparison of Energy Intake in Toddlers Assessed by Food Frequency Questionnaire and Total Energy Expenditure Measured by the Doubly Labeled Water Method

Clare E. Collins, PhD; Tracy L. Burrows, PhD, AdvAPD; Helen Truby, PhD, AdvAPD; Philip J. Morgan, PhD; Ian M. R. Wright, PhD; Peter S. W. Davies, PhD; Robin Callister, PhD

ARTICLE INFORMATION

Article history:
Accepted 21 September 2012
Available online 11 January 2013

Keywords:
Dietary assessment validation
Doubly labeled water
Food frequency questionnaire
Comparison of toddler energy intake

2212-2672/$36.00
doi: 10.1016/j.jand.2012.09.021

ABSTRACT
The ability of parents to accurately report energy intake in toddlers has rarely been validated using the gold-standard doubly labeled water (DLW) method to assess total energy expenditure (TEE). The aim of the study was to evaluate the accuracy of toddler energy intake (EI), estimated using the Australian Child and Adolescent Eating Survey (ACAES) food frequency questionnaire (FFQ) by parent report compared with a weighed food record (WFR) and TEE measured by DLW. Twelve toddlers had TEE assessed over 10 days using DLW. Usual energy intake was estimated by the primary caregiver, using standard toddler portions in ACAES-FFQ and a 4-day WFR and daily EI (in kilocalories) derived using national nutrient databases. Accuracy of reporting was calculated from absolute (EI-TEE) and percentage (EI/TEE×100) differences between EI and TEE and Pearson correlations and limits of agreement from Bland-Altman plots. Toddlers (n=12, 7 boys) had a mean age of 3.2±0.5 years, body mass index 16.2±0.9 kg, body mass index *z* score 0.1±0.8, EI from ACAES-FFQ 1,183±281kcal/day, and WFR 1,179±278 kcal/day and DLW TEE 1,251±149 kcal/day. The mean difference and limits of agreement (±2 standard deviations) compared with DLW was −68 (−623, 488) kcal/day for the FFQ and for the WFR −72 (−499, 354) kcal/day. Although both a semiquantitative FFQ and WFR can adequately estimate toddler energy intake at the group level in this population, toddler-specific portion size estimates should be assigned to foods listed in the FFQ. Choice of method is likely to depend on practical issues, including cost and burden.
J Acad Nutr Diet. 2013;113:459-463.

ASSESSING DIETARY INTAKE IN YOUNG CHILDREN aged between 2 and 3 years of age is particularly challenging due to specific factors including variable food portion sizes and distribution of food and drink intake across the day,[1] foods and beverages consumed outside of the home (eg, at childcare), and factors related to parental or caregiver recall of foods.[2] Assessing validity of dietary intake determines the accuracy or precision of a measure of intake and is assessed by comparing values obtained by a test instrument to a gold standard measure of known validity. For total energy expenditure (TEE) the doubly labeled water (DLW) method is the accepted gold standard[3] and the preferred approach in free-living individuals. However, due to the high costs and level of technical and analytical expertise required, as well as the challenges of collecting daily urine samples from toddlers, this level of evaluation is rare and it is not surprising that most studies using this technique have <20 subjects.[4] In a review of validation studies using the gold standard method of DLW, only four out of 15 studies were conducted in children aged ≤4 years.[5-8] Just one study, conducted in 1994, evaluated the validity of energy intake estimated by a food frequency questionnaire (FFQ) in 45 children aged 4 to 7 years,[8] with the FFQ found to significantly over-report intake in the majority of participants. However, the FFQ did have a reporting period of 1 year[8] and, hence, did not directly relate to the DLW urine collection period and further, adult portion sizes were used in the FFQ estimation of energy intake (EI).[8] Comparative validation is more commonly conducted by comparing two dietary assessment methods, with a weighed food record (WFR) most commonly used as the reference method.[3]

The Australian Child and Adolescent Eating Survey (ACAES) is a child-specific FFQ previously developed and validated in children aged 9 to 16 years,[9-11] but its utility for the toddler age group has not been assessed. Therefore, the primary aim of this study was to evaluate the accuracy of toddler EI, estimated using the toddler version of the ACAES FFQ by parent-report compared with TEE measured by DLW, in children aged 2 to 3 years. A secondary aim was to compare energy intake as assessed by a WFR with TEE measured by DLW.

SUBJECTS AND METHODS

Participants

Twelve families with a child aged approximately 3 years were recruited from the Hunter region, New South Wales, Australia, from February to November, 2010. Families were eligible to participate if toddlers were a healthy weight (defined by age- and sex-specific body mass index [BMI] 14.4-18.3[12]), one eligible parent or caregiver (defined as residing permanently with the child) was willing and able to attend all assessment sessions, and toddlers had no known medical conditions or medications affecting body weight, metabolic rate, or appetite. Inclusion criteria aimed to specifically reduce subject heterogeneity, given the high costs associated with the DLW technique. Parents provided written informed consent before baseline assessments. Ethics approval was obtained from the University of Newcastle Human Research Ethics Committee.

Study Design and Data Collection

All families attended the university laboratory on Day 1 (baseline) and on Day 10 of the data collection period. Child participants fasted overnight before the baseline visit. During the data collection period, parents/caregivers were advised to maintain usual eating patterns and physical activity habits for their toddler to facilitate weight stability. Parents were telephoned once during the data collection period by a member of the research team to check how they were progressing with the study measures.

Outcome Measures

Dietary intake. One parent/caregiver completed the toddler version of the ACAES FFQ under supervised conditions to estimate usual child intake. ACAES is a semiquantitative FFQ and asks about usual intake frequency of 120 food items during the previous 6 months. It was developed and initially validated for use with older Australian children and adolescents.[9-11] In the toddler version, standard toddler portion sizes replaced the child portion size for each food item and were derived from the toddler age group from the 2007 National Children's Nutrition and Physical Activity Survey (purchased from the Australian Social Science Data Archive, Australian National University). For prepackaged foods with a standard serving size, such as muesli bars and dried fruit bars, the standard portion size was retained. The frequency options ranged from "never" up to "4 or more times per day" for foods and up to "7 or more glasses per day" for some beverages. Data from ACAES FFQ were scanned and total EI computed using the Australian AusNut 1999 database (All Foods) Revision 14 and AusFoods (Brands) revision 5 database (Australian New Zealand Food Authority).

Child EI was simultaneously assessed using a 4-day WFR kept by the parent, primarily the mother, which included at least 1 weekend day. At baseline parents were provided with detailed instructions from an Accredited Practising Dietitian on how to complete the WFR. Parents were provided with a set of electronic kitchen scales (Venezia, Soehnle-Waagen GmbH & Co) that weigh in 1-g increments up to 2 kg, as well as a record book to record the results. WFRs were checked for completeness at Day 10 with clarifications made with the parent or caregiver. Mean daily energy intake was derived using the same nutrient databases as described for the ACAES FFQ.

DLW. TEE was measured using the DLW method as described in detail elsewhere.[13] Briefly, background isotope levels were determined at baseline with a urine sample collected in the laboratory before dosing with DLW. Subjects were then given an oral loading dose of DLW (^2H_2O and $H_2{}^{18}O$), corresponding to 0.083g $^2H_2$ (99.8 atom % excess; Sigma Aldrich) and 1.3g ^{18}O (10 atom % excess; Taiyo Nippon Sanso) per kilogram of measured body weight. The isotope dose was measured in grams to three decimal places. A second urine sample was obtained approximately 5 hours postdose, and daily urine samples collected for 9 consecutive days with parents recording the sample collection time. Urine samples were frozen (−20°C) until analyzed on an Isoprime Dual Inlet Stable Isotope Ratio Mass Spectrometer. The multipoint approach was used to calculate TEE as previously described.[14] All samples were analyzed in duplicate with laboratory standards calibrated against an international suite of waters including Vienna Standard Mean Ocean Water,[14] with results reported as percent relative to Vienna Standard Mean Ocean Water, with an analytical uncertainty better than ±3% (1 standard deviation) and ±0.5% (1 standard deviation), for ^2H and ^{18}O, respectively. Carbon dioxide production was derived from ^2H and ^{18}O disappearance rate constants calculated by least squares regression analysis.[15] TEE was calculated by the DeWier equation using the rates of carbon dioxide production and the respiratory quotient.[15]

Other Measures. Height was measured using a Harpenden portable stadiometer (Holtain Limited) to 0.1 cm using the stretch stature method at baseline.[16] Weight was measured to 0.01 kg on a digital scale (CH-150kp, A&D Mercury Pty Ltd), in light clothing and without shoes, at baseline. BMI on Day 1 was calculated using the standard equation with BMI *z* scores determined using the least mean square method of LMS Growth (version 2.12, 2002, Medical Research Council).

Data Analysis. Data are presented as mean±standard deviation, median (range) were analyzed with SPSS version 19 (2009, SPSS Inc). The accuracy of energy intake derived from both the FFQ and WFR was assessed by calculating the absolute (ie, [EI-TEE] and percentage difference [EI/TEE]×100) from the method of DLW. The associations between EI from the FFQs and WFR with TEE were tested using Pearson correlations, to determine if the measures were related. Bland-Altman plots were produced[17] to visually interpret agreement between the measures. These plots indicate the direction of bias and if it is consistent across intake levels. The limits of agreement (mean difference ±2 standard deviations for the difference between measures) determine if the agreement between the two methods is acceptable.[18] Interpretation of Bland Altman plots was based on categories defined by Tang[19] and used previously in validation studies.[9] Good agreement is shown when the difference between the two measures is approximately ≤1 standard deviation, Fairly good agreement is shown when the difference is equal to 2 standard deviations, and bad or poor agreement is when the differences are ≥3 standard deviations. Pearson correlations were tested between the averages and differences of the each of the two measures (ie, FFQ vs DLW and WFR vs DLW) to determine whether the difference between the two measures is dependent on initial value.

Table. Comparison of energy intake (EI) in toddlers assessed by food frequency questionnaire (FFQ) and total energy expenditure (TEE) measured by the doubly labeled water (DLW) method

Measure	Mean±standard error	Median	Range
TEE (kcal/d)	1,251±149	1,246	1,037-1,452
FFQ (kcal/d)	1,183±280	1,255	802-1,607
WFR[a] (kcal/d)	1,179±278	1,288	666-1,485
EI FFQ–TEE (kcal)	−68±278	95	−440-433
EI WFR–TEE (kcal)	−72±213	−78	−461-254
EI FFQ/TEE (%)	95±23	93	70-142
EI WFR/TEE (%)	94±19	94	59-123

[a]WFR=weighed food record.

Participants were identified as under-reporters of EI based on the 95% confidence limits of the expected EI:TEE of 1.[20] The 95% confidence limits were calculated as follows:

$$\pm 2 \times \sqrt{[(CV_{EI}^2/D + (CV_{TEE}^2)]}$$

where CV_{EI} is the within-subject coefficient of variation (CV) for EI from an FFQ (23%),[21] and CV_{TEE} is the within-subject CV for TEE (8.8%). D is the number of days of dietary assessment; however, because FFQs are used to capture habitual intake, D is defined as infinity.[20] Therefore, participants with EI:TEE<0.82 were classified as under-reporters of EI, those with EI:TEE>1.18 were classified as over-reporters and those within the range were considered adequate reporters.

RESULTS AND DISCUSSION

Twelve parent–toddler dyads were recruited. The toddlers were all white (n=12, 7 boys) had a mean age 3.2±0.5 years, BMI 16.2±0.9, and BMI *z* score 0.11±0.8. Adult participants were all biological parents with the majority being mothers (n=8) with both parents (mother and father) involved for (n=4) toddlers. Descriptive statistics for toddler EI derived from TEE from DLW, the parent-reported toddler version of the ACAES FFQ, and the WFR and are summarized in the Table.

The Pearson correlation coefficient between EI (measured by FFQ) and TEE (measured by DLW) was not significant (r=0.29; P=0.37). The relationship between WFR with TEE (measured by DLW) was stronger (r=0.65; P=0.02), indicating that the WFR and DLW assessments have a moderately strong linear relationship.

Figure 1A and 1B display the Bland-Altman plots, demonstrating the average difference between the two methods being compared against the mean difference between them, in this case EI (from FFQ or WFR) and TEE assessed by DLW. The limits of agreement (LOA) plus 2 standard deviations were wide for both the FFQ and WFR comparison indicating a lower level of agreement between the measures at the individual level. However, at the group level all values for both the FFQ and WFR fell within 2 standard deviations of the LOA, indicating fairly good agreement[20] with the DLW method, indicating both methods are acceptable to evaluate energy intake at the group level. Future studies with larger sample sizes and differing population characteristics are needed to substantiate the validity of ACAES FFQ in other population subgroups because dietary intakes have been shown to differ by ethnicity.[22,23]

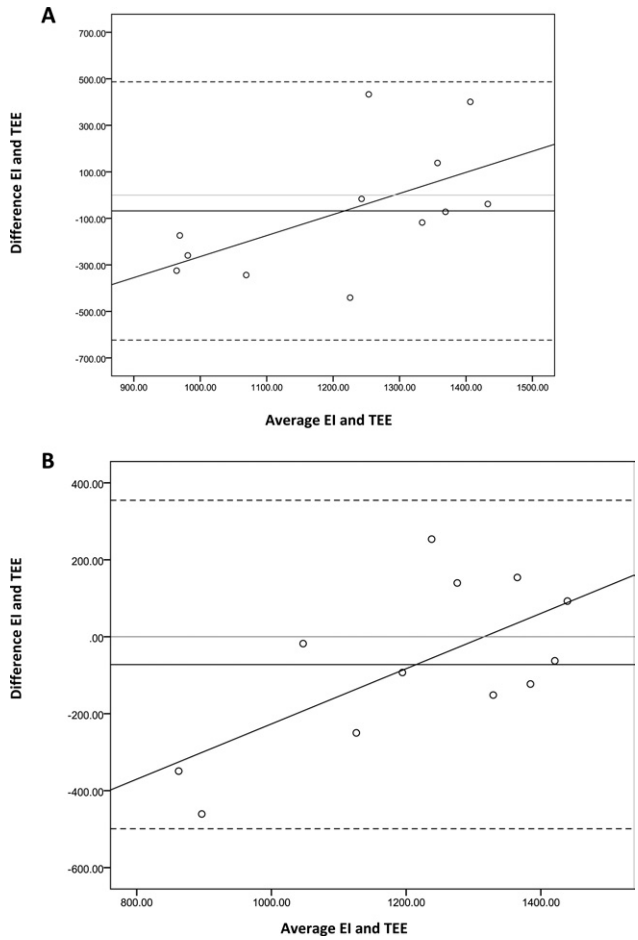

Figure 1. (A) Bland-Altman plot between food frequency questionnaire energy intake (EI) and doubly labeled water total energy expenditure (TEE) (kcal). The solid dark line represents the mean difference with dotted lines representing ±2 standard deviations (limits of agreement). The solid light line is equal to 0, which indicates absolute agreement. Correlation value 0.58; P=0.05. (B) Bland-Altman plot between weighed food record energy intake (EI) and doubly labeled water total energy expenditure (TEE) (kcal). The solid dark line represents the mean difference with dotted lines representing ±2 standard deviations (limits of agreement). The solid light line is equal to 0, which indicates absolute agreement. Correlation value 0.66; P=0.02.

Results of this study are comparable with DLW validation studies in young children using other dietary assessment methods such as food records, diet history, and 24-hour recalls.[5-7] Specifically, the LOA for the FFQ in our study (−2.6, 2.0MJ) compared with DLW are narrower than that previously reported for an FFQ in a sample of 45 children aged 4 to 7 years (−1.58, 9.57 MJ).[8] This improvement in ACAES FFQ may be due to the use of toddler-specific portions sizes and the shorter (6 months) reporting period used to estimate en-

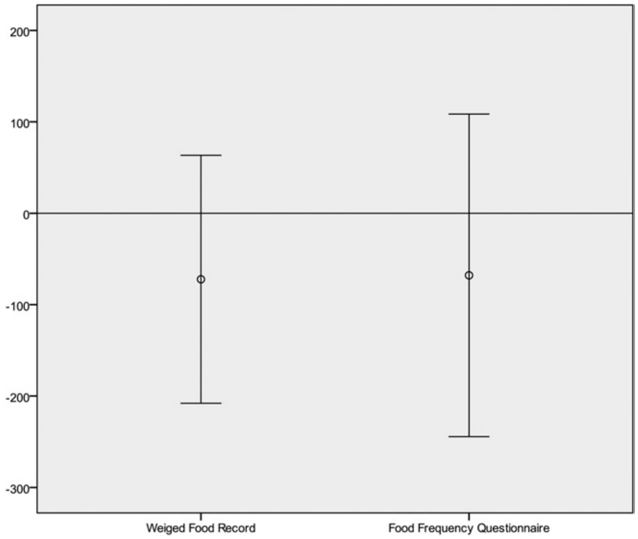

Figure 2. Level of bias between weighed food record and food frequency questionnaire when compared with gold standard doubly labeled water method. The solid line 0 indicates no difference.

ergy intake, rather than the previous study that used an FFQ with adult portion sizes and a 12-month recall period.[8]

Significant correlations were found between total energy as the mean of the two methods being compared (FFQ or WFR and DLW) vs the difference between these two methods (r=0.58; P=0.05 for FFQ and for WFR r=0.66; P=0.02). This indicates that the energy intake related bias is in the same direction for both comparisons (FFQ or WFR), with under-reporting more evident at lower energy intakes and over-reporting more evident as energy intake increases as illustrated in Figure 1A and 1B. However, for toddlers both the FFQ and WFR appear to exhibit a similar degree of bias. This has implications for research studies where collection of weighed food records is not a feasible option. It suggests that at the group level toddler FFQs that incorporate population-specific toddler portion size estimates may be a useful and practical alternative.

The mean difference and LOA when compared to DLW for each dietary method was 68 (−623, 488) kcal/day for the FFQ (95±24% of TEE) and for the WFR −72 (−499, 354) kcal/day (94 ±19% of TEE). The relative bias of each method compared to DLW is shown in Figure 2. Here the level of difference for each measure is in the same direction, but the 95% CI is wider for the FFQ. Although this has not been demonstrated previously for a toddler-specific FFQ, the finding is similar to a previous study in 150 children (both Hispanic and non-Hispanic), using a 3-day WFR in younger children (<2 years).[1] Classification of mis-reporters using cutpoints for the FFQ were under-reporters (n= 4) or 33%, adequate reporters (n=6) or 50%, and 17% over-reporters (n=2). For the WFR 25% (n=3) were classified as under-reporters, 67% adequate reporters (n=8), and one over-reporter (8%).

A secondary aim was to compare the performance of the FFQ with the commonly used 4-day WFR. Our study suggests that the FFQ was practically equivalent in terms of accuracy compared with the WFR. This is surprising given the detail related to specific foods and portion sizes obtained from an accurately completed WFR compared with that of an FFQ and may reflect both the differential burden and biases associated with each method.[3]

Limitations of this study relate to sample size, although this is comparable to other DLW studies in children.[4] Future studies should recruit larger and more diverse population groups to assess validity of FFQs. In addition, the DLW method assessed a 10-day energy expenditure period, which may not represent habitual energy expenditure, nor reflect the 6-month reporting period of the FFQ. Although a random convenience sample of healthy toddler children was chosen, it is likely that for some participants this was a period of low physical activity and for some a period of relatively high activity and the two measures do not cover the same periods.

CONCLUSIONS

This study should give practitioners confidence that parents can provide important information about their toddlers food intake and that fathers in particular can adequately report on their child's diet. Either a parent completed FFQ or WFR can be used to adequately estimate toddler energy intake at the group level. However, if using an FFQ, toddler-specific portion size estimates should be used. Importantly, the DLW method and collection of dietary intake data can be undertaken successfully in toddlers. Parents can be actively engaged in optimizing data quality by familiarizing them and their toddlers with procedures during an initial laboratory visit. Further support via telephone contact can trouble shoot issues, remind parents to continue with data collection, and reinforce the importance of reporting food intake and timing of urine specimen collection as accurately as possible. Further studies evaluating the accuracy of parent-reported toddler energy intake in larger and more ethnically diverse population samples, using a range of dietary intake assessment methods and including biomarkers, are required. Currently, selection of the most appropriate method is likely to depend on the practical issues such as practitioner or researcher expertise, cost, and participant burden.

References

1. Fisher J, Butte N, Mendoza P, et al. Overestimation of infant and toddler energy intake by 24 hour recall compared with weighed food records. *Am J Clin Nutr*. 2008;89(3):928.
2. Livingstone MB, Robson P, Wallace J. Issues in dietary assessment in children and adolescents. *Br J Nutr*. 2004;92(supp 2):S213-S222.
3. Willett W. *Nutritional Epidemiology*. 2nd ed. New York, NY: Oxford University Press; 1998.
4. Burrows T, Martin R, Collins C. A systematic review of the validity of dietary assessment methods in children when compared with the method of doubly labelled water. *J Am Diet Assoc*. 2010;110(10): 1501-1510.
5. Reilly J, Montgomery C, Jackson D, MacRitchie J, Armstrong J. Energy intake by multiple pass 24h recall and total energy expenditure: A comparison in a representative sample of 3-4-year-olds. *Br J Nutr*. 2001;86(5):601-605.
6. Livingstone MBE, Prentice AM, Coward WA, et al. Validation of estimates of energy intake by weighed dietary record and diet history in children and adolescents. *Am J Clin Nutr*. 1992;56(1):29-35.
7. Lanigan JA, Wells JCK, Lawson MS, Lucas A. Validation of food diary method for assessment of dietary energy and macronutrient intake in infants and children aged 6-24 months. *Eur J Clin Nutr*. 2001; 55(2):124-129.

8. Kaskoun M, Johnson R, Goran M. Comparison of energy intake by semiquantitative food-frequency questionnaire with total energy expenditure by the doubly labeled water method in young children. *Am J Clin Nutr*. 1994;60(1):43-47.
9. Watson J, Collins C, Sibbritt D, Dibley M, Garg M. Reproducibility and comparative validity of a food frequency questionnaire for Australian children and adolescents. *Int J Behav Nutr Phys Act*. 2009;6(1):62.
10. Burrows T, Berthton B, Garg M, Collins C. Validation of food frequency questionnaire using red blood cell membrane fatty acids. *Eur J Clin Nutr*. 2012;66(7):825-829.
11. Burrows TL, Warren JM, Colyvas K, Garg ML, Collins CE. Validation of overweight children's fruit and vegetable intake using plasma carotenoids. *Obesity*. 2008;17(1):162-168.
12. Cole T, Bellizzi M, Flegal M, Dietz W. Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ*. 2000;320(7244):1240-1243.
13. Davies PS, Coward WA, Gregory J, White A, Mills A. Total energy expenditure and energy intake in the pre-school child: A comparison. *Br J Nutr*. 1994;72(1):13-20.
14. Coward WA. Stable isotopic methods for measuring energy expenditure. The doubly-labelled-water (2H2(18)O) method: Principles and practice. *Proc Nutr Society*. 1988;47(3):209-218.
15. Schoeller DA, Hnilicka JM. Reliability of the doubly labeled water method for the measurement of total daily energy expenditure in free-living subjects. *J Nutr*. 1996;126(1):348S-354S.
16. Marfell-Jones M, Olds T, Stewart A, Carter L. *International Standards for Anthropometric Assessment*. Potchefstroom, South Africa: International Society for the Advancement of Kinanthropometry; 2006.
17. Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476): 307-310.
18. Gibson R. *Principles of Nutritional Assessment*. 2nd ed. Oxford, UK: Oxford University Press; 2005.
19. Tang H. *Diet, Physical Activity, Environments and thier Relationship to the Emergence of Adolescent Overweight and Obesity in Ho Chi Minh City, Vietnam*. Callaghan, New South Wales, Australia: University of Newcastle; 2005.
20. Black AE, Cole TJ. Within- and between- subject variation in energy expenditure measured by the doubly labelled water technique: Implications for validating reported dietary energy intake. *Eur J Clin Nutr*. 2000;54(5):386-394.
21. Scagliusi F, Ferriolli E, Pfrimer K, et al. Underreporting of energy intake in Brazilian women varies according to dietary assessment: A cross-sectional study using doubly labeled water. *J Am Diet Assoc*. 2008;108(12):2031-2040.
22. Ziegler P, Hanson C, Ponza M, Novak T, KH. Feeding Infants and toddler study: Meal and snack intakes of hispanic and non hispanic infants and toddlers. *J Am Diet Assoc*. 2006;106(suppl 1):S107-S123.
23. Briefel R, Ziegler P, Novak T, Ponza M. Feeding Infants and toddlers: Characteristics and usual nutrient intakes of hispanic and non hispanic infants and toddlers. *J Am Diet Assoc*. 2006;106(supp 1):S84-S95.

AUTHOR INFORMATION

C. E. Collins is a professor and T. L. Burrows is a lecturer, School of Health Sciences, and R. Callister is a professor, School of Biomedical Sciences and Pharmacy, all with the Faculty of Health and Priority Research Centre in Physical Activity and Nutrition, The University of Newcastle, Callaghan, New South Wales, Australia. H. Truby is a professor, Department of Nutrition and Dietetics, Southern Clinical School of Medicine, Monash University, Victoria, Australia. P. J. Morgan is a professor, School of Education, Faculty of Education and Arts and Priority Research Centre in Physical Activity and Nutrition, The University of Newcastle, Callaghan, New South Wales, Australia. I. M. R. Wright is an associate professor, School of Medicine and Public Health, Faculty of Health, The University of Newcastle, Callaghan, New South Wales, Australia, and a senior staff specialist neonatologist, John Hunter Children's Hospital and the Mother and Babies Research Centre, Hunter Medical Research Institute, Rankin Park, New South Wales, Australia. P. S. W. Davies is a professor, Children's Nutrition Research Centre, School of Medicine, University of Queensland, Brisbane, Queensland, Australia.

Address correspondence to: Clare E. Collins, PhD, School of Health Sciences, Faculty of Health, University of Newcastle, HA12 Hunter Building, University Dr, Callaghan, Newcastle, NSW, Australia, 2308. E-mail: Clare.Collins@newcastle.edu.au

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT

This study was supported from a Hunter Children's Research Foundation and Hunter Medical Research Institute grant and researcher support from a National Health and Medical Research Council Career Development Fellowship.

ACKNOWLEDGEMENTS

The authors thank Caitlin West for assistance with data collection and Hannah Lucas and Brendan Marshall for assistance with data entry and manipulation.